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A COMBAT BATTLE DAMAGE ASSESSOR EXPERT SYSTEM

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ABSTRACT

Weapons to defend against aircraft are more powerful and accurate than ever before. Aircraft systems and structures have become more sophisticated than those in World War II. With all these technological improvements, a war may be won or lost within the first few hours or days of battle. Therefore, it is necessary that as many aircraft as possible be available for each mission. But, with the new materials and manufacturing methods, the battle damage assessor is ill equipped to do his job, that of assessment and repair. Repairs which restore full strength and life to a structure are inappropriate. This paper presents a battle damage assessor expert system. The system is designed to provide the expertise of a structural engineering consultant to the damage assessor technician.

INTRODUCTION

The nature of battle in the world has been constantly changing since the days of WW II. The aircraft of World War II were capable, but they cannot compare to the composite structure, high speed, electronic marvels of today's aircraft.

It has been found that a war today may be very short, like the Arab-Israeli 6 day war. Also, the war may be won or lost in the first few hours or days. It is because of this that the combat battle damage assessor concept came into being. The idea here is to determine how much damage has happened to the aircraft, whether it can be flown with only cosmetic repairs, whether it can be fixed for the next mission within 24 hours, whether it cannot be fixed at all, or whether it should receive just enough repair to allow it to be flown to a rear area for complete repair. The goal is to have as many aircraft as possible available for the next mission. Any nonmission essential equipment may be left unrepaired or disabled. This concept is diametrically opposed to the normal maintenance operations of peacetime.

Let's examine the need for this system. Photograph 1 shows a comparison between two panels, one made of aluminum and the other made of graphite/epoxy. It is easily seen that there is apparently more damage done to the graphite panel. Photograph 2 shows two views of a graphite/epoxy panel which has been shot. One view is the entrance side of the projectile, the side which would typically present itself to the assessor. At first inspection, there does not appear to be too much damage. On the other side we see that there has been extensive damage. It is important that the damage assessor know the extent of the damage so that adequate repairs can be made. The battle damage assessor expert system will be able to contend with this type of problem. As a point of reference, Photographs 3 and 4 show the damage done to a graphite/epoxy vertical stabilizer, while Photographs 5 and 6 show typical damage done to aluminum structure. These photographs are meant to show the difference in the type of damage between aluminum and composite structures, they cannot be used as a comparison of the two material systems.

This paper will present work that is being conducted in the Flight Dynamics Laboratory to produce an automated battle damage assessor. It should be noted that this system is not designed to operate without human intervention, nor is it an automated database containing the Technical Orders (TOs), as is being done by Human Resources Laboratory. Rather, it is designed to be a structural consultant to the trained technician in the assessment and repair of the airframe.

The paper begins with a brief discussion of the concept of battle damage assessment. This is a broad overview to familiarize the reader with the basic concepts involved. Next, the requirements for the battle damage assessor software are presented. Some of the requirements presented were developed by McDonnell Douglas Astronautics Co. under contract to the Human Resources Laboratory [WILPER 1983]. The paper concludes with a discussion of the proposed system. This design
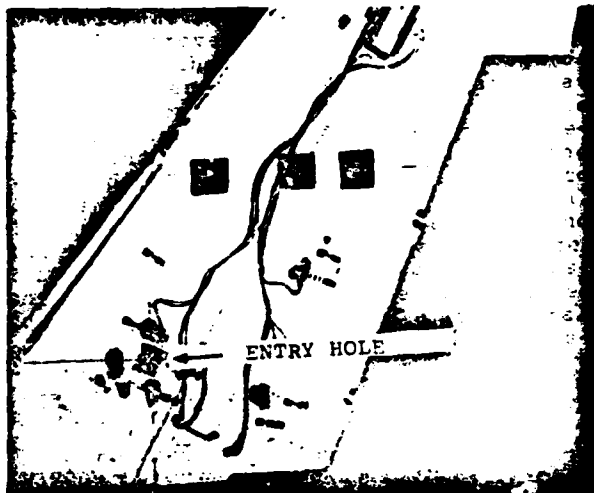
PHOTOGRAPH #1
Comparison of Graphite/Epoxy and Aluminum panels.
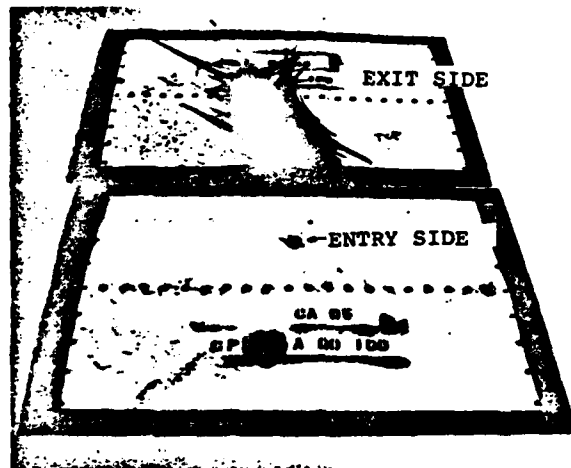
PHOTOGRAPH #2
Entry side and exit side damage - Graphite/Epoxy panel.
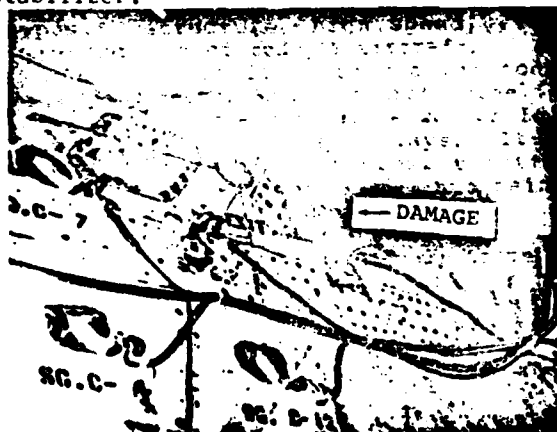

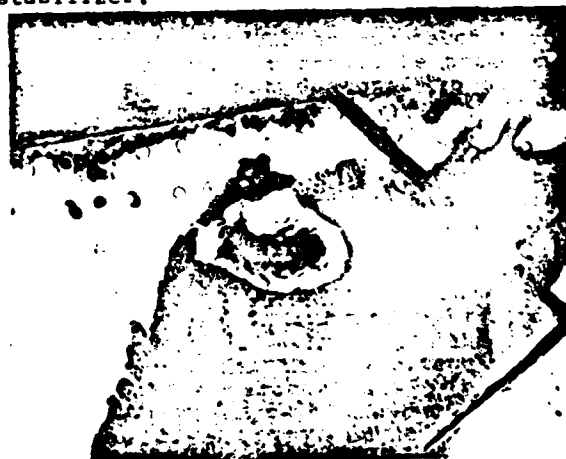**PHOTOGRAPH #3**
Entry damage Graphite/Epoxy vertical stabilizer.

PHOTOGRAPH #4
Exit damage Graphite/Epoxy vertical stabilizer.

PHOTOGRAPH #5
Entry damage - Aluminum structure.

PHOTOGRAPH #6
Entry damage - Aluminum structure.

is high level and is likely to change with the development of the specific software modules.

In reviewing the literature, it is apparent that there is no consensus of opinion as to what is really required or what will actually be sufficient. As is typical of many advanced projects, a system must be implemented, and used before the final requirements and configuration can be worked out.

BATTLE DAMAGE ASSESSOR CONCEPT

In modern warfare, with missiles able to strike any location in the world in less than thirty minutes, and with the destructive power of these weapons, it becomes apparent that a war may easily be won within the first few days. This being the case, it is necessary to provide the armed forces with as much usable equipment as possible during this time frame. Aircraft have been found to be a very valuable asset in wartime. However, the sophistication of the equipment provided to the ground troops makes the possibility of damage to aircraft very great. It becomes necessary, therefore, to repair and get these aircraft back in service as quickly as possible. During peacetime, the repairs made to aircraft have been done with the goal of restoring the aircraft to full usefulness and life. During conflict, this goal must be changed. The new goal must be to repair the aircraft as quickly as possible to enable it to at least fly the next mission. It is to this end that the battle damage assessor concept has been developed.

Aircraft Battle Damage Repair Program

The Air Force has responded to the need for quick repair of combat aircraft by issuing the USAF Concept for Aircraft Battle Damage Repair (ABDR). This program calls for postponing any routine maintenance which is not absolutely necessary to the integrity of the aircraft, and accomplish only those repairs essential to make the aircraft mission capable. Figure 1 [WILPER 1983] shows this overall battle damage assessment process. In the past, there has been the need to repair more aircraft than manpower and resources could handle. This need has been met through the use of innovative repairs and substitutions. Each innovative repair has required the ranking maintenance technician to assume the approval authority for each modification. The implementation of the ABDR concept will encourage innovation as well as placing the tools, materials, and techniques to make the non-standard repairs in the technician's hands.

Additionally, implementation of the ABDR concept assures development of proper and adequate short term repairs so that

the repair is based on sound engineering principles and not a function solely of the skill and judgement of the individual technician. By developing standards and evaluating prior work, variability in ABDR performance should be reduced and the overall quality of repairs improved.

Much work has been done in the area of ABDR. A Technical Order (TO) has been developed which addresses the general information and techniques which are applicable to all aircraft. One of the most significant contributions of this effort has been the development of a simple, effective and unambiguous method for identifying and describing assessed damage which is universally applied by any assessor to any aircraft.

Much of ABDR is involved with the repair or deferred repair of aircraft structures. Generally speaking, a maintenance technician cannot be expected to have the engineering expertise to judge the stresses sustained by various areas of the aircraft. Therein lies part of the justification for this effort. Our goal is to provide the technician with a structural engineering consultant in the form of an expert system.

Training Programs

All assessor candidates are required to be trained first as technicians. Ideally, the assessors would be engineers, however, with the current shortage of skilled engineers in the workforce today, there will likely be an inadequate number of these trained people for use in the ABDR program. Further, when armed conflict occurs, there will be an insufficient amount of time to train new people in the area of ABDR. It becomes necessary to have as many trained assessors as possible in the standing armed forces. To reduce the training required and the possibility of errors being made, the Air Force is developing an automated tool to augment the human assessor in the evaluation and design of repairs and analysis of damage to aircraft. This automated device will be the equivalent of a structural engineer.

Currently all ABDR assessors are required to complete training at a Combat Logistics Support Squadron (CLSS) and be certified. This course is only offered to very experienced senior technicians. The course is two weeks long with one week of classroom training, followed by one week of hands on experience. It should be noted that this program is in its infancy and will need refinement as new tools and techniques are developed.

Assessor Environment

Since the combat battle damage assessor will be working in forward battle

areas, the environment will be harsh. The typical assessor may be required to work in areas being subjected to both chemical and biological agents. It may be necessary for the assessor to perform his duties while wearing chemical defense ensemble (CDE). Due to the type of equipment, and the expected damage and inspection requirements, this ensemble may limit the effectiveness of the assessor and the type of equipment that he may be able to use. It will be necessary for the expert system to be designed with these limitations in mind.

It should be emphasized, that this concept (ABDR) will not be employed during peacetime or routine operations of aircraft. During war it is the goal of the program to make available the greatest number of aircraft per mission during the first few days of armed conflict.

HIGH-LEVEL SYSTEM DESIGN

Flight Dynamics Laboratory has been working on developing two programs. The first program is a design analysis program. Since the structure which the battle damage assessor is working has been designed, the design process for the repair can be greatly simplified. The analysis program has been designed to take the input model of the undamaged structure, and the description of the damage as the main input. The analysis program then modifies its internal representation of the structure due to the damage, and produces the resultant structural capabilities of the damaged structure.

A second program is also being developed at Flight Dynamics Laboratory for the automatic design of repairs for damaged structure. It should be noted,
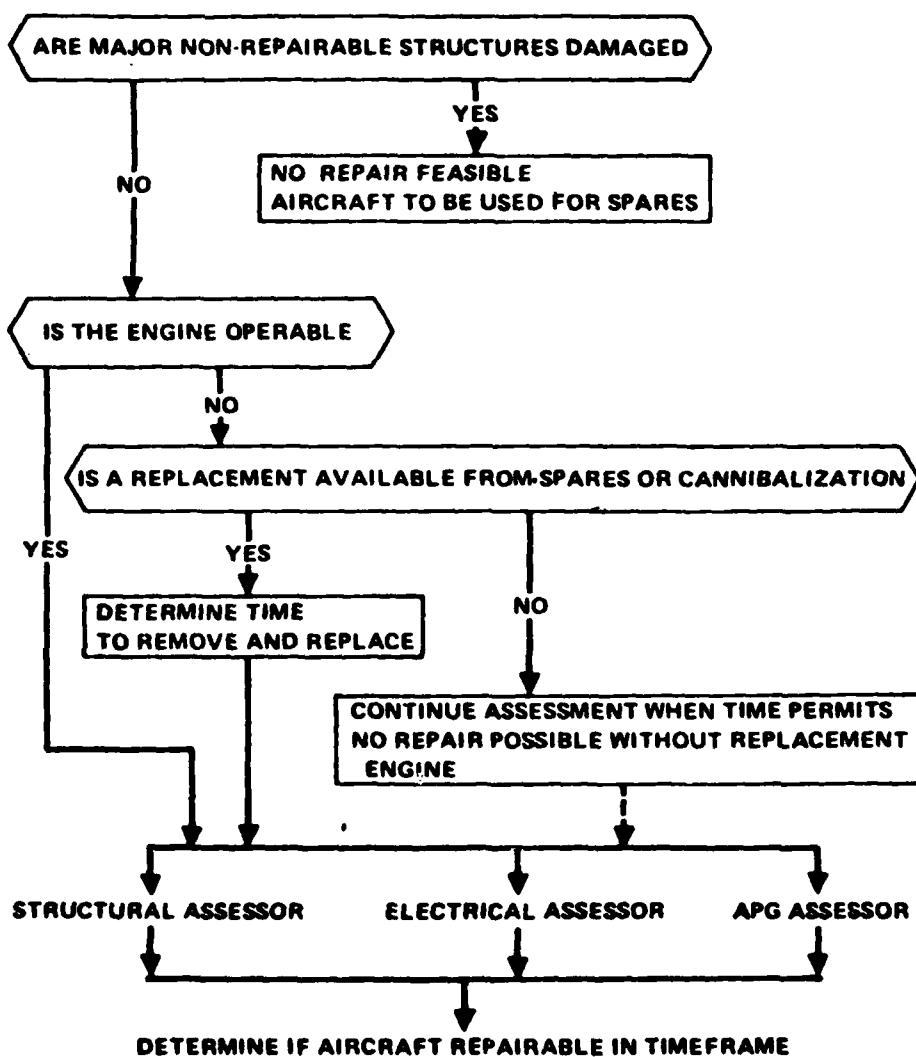

FIGURE 1. OVERALL ASSESSMENT PROCEDURE

however, that there is no analysis associated with this program. In essence this program acts like a database of previous designs in recommending a repair.

Where the battle damage assessor expert system comes in, is in the area of combining these two programs to answer the following questions:

(1) Does the aircraft need to be repaired?
(2) What is the best repair?
(3) Is the proposed repair adequate?
(4) Can the repair be completed within the time limit?

(5) Are the materials and skills necessary available?

In other words, the battle damage assessor program provides the intelligence which, in all likelihood, will not be available in the field. The one item which makes the programming of the design engineer (for the design of the repair) difficult, is that the design process is not easily documented. It is a process which takes place within the human mind, and becomes better with experience. It is necessary for the battle damage assessor program to

FIGURE 2. STRUCTURAL ASSESSOR.

perform as a human design engineer would. This will require a large database of facts along with the interaction of a human technician. This process is made somewhat easier due to the fact that the computer is not required to design the whole structure, but only to design a repair for the damaged structure. With the use of the two programs being developed by Flight Dynamics Laboratory this process is well on the way to being achieved. It will be necessary for the battle damage assessor program to provide the intelligent interface between these two programs.

This section presents the high level system design of the combat battle damage assessor software, Figure 3. This is meant to be a first cut at the design and will require further refinement as the implementation progresses. Each section corresponds to the three sections normally associated with an expert system.

Knowledge Base

This section describes the information required to be in the knowledge base in order for the cognitive engine to function. A problem arises in the area of the analysis program being developed by Flight Dynamics Laboratory. Should this program be in the knowledge base or the cognitive engine? It is my contention that the analysis program should be viewed as part of the knowledge base along with the program to determine the repair. The cognitive engine can then consult with the program just as one might with an expert. Give it facts and it gives back results. The results are then interpreted by the heuristics of the system. The knowledge base is where the expert knowledge is to reside.

The knowledge base must contain, in addition to the two programs previously described, the aircraft specific TOs. The TOs contain the entire maintenance procedures and parts lists required for the ongoing maintenance of the given aircraft. In addition, there are battle damage assessor TOs which are generic, they apply to all aircraft. These TOs contain general procedures to assess damage and make general repairs and material substitutions.

The knowledge base will also contain the usual production rules (heuristic knowledge) which describe the IF-THEN type constructs which are so common in expert systems. In this case the production rules will have to be slightly different than one might find in a diagnostic system which is common in the maintenance and medicine. It is necessary to define the knowledge of the engineer in these produc-

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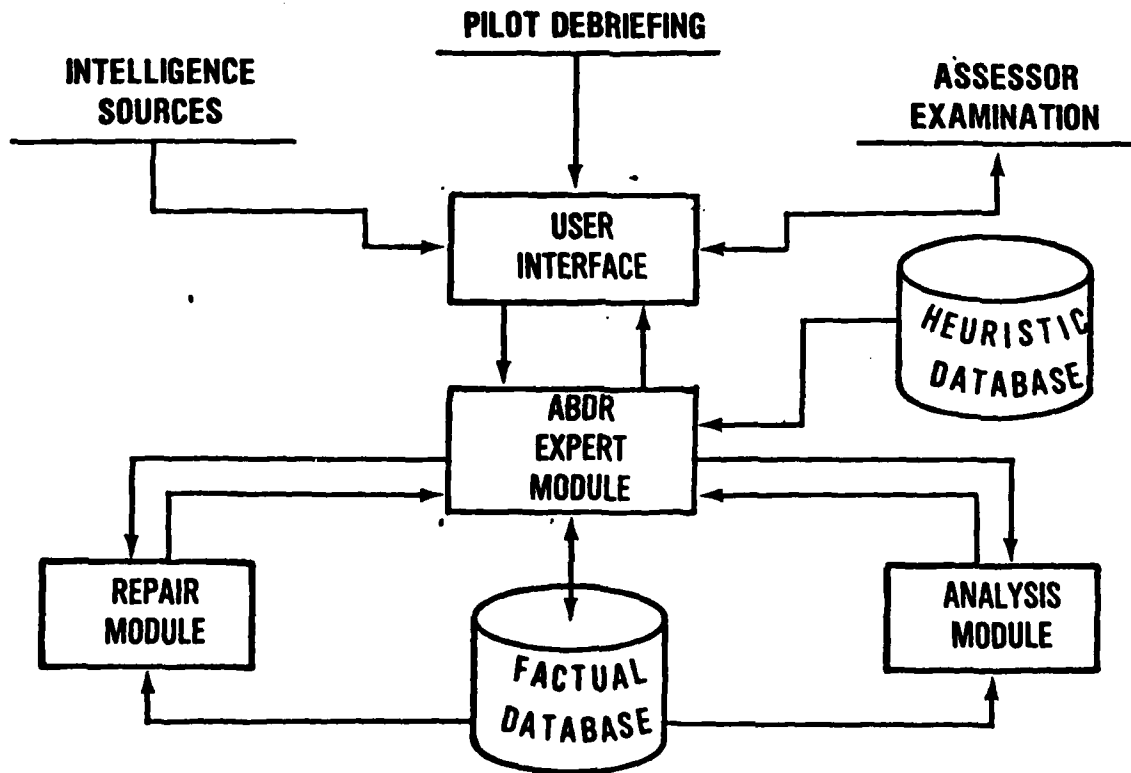
INTELLIGENCE SOURCES

ASSESSOR EXAMINATION

FIGURE 3. CONCEPTUAL SYSTEM.

tion rules. This is a difficult process because the actions and decisions made by an engineer have not been formalized or quantified. Another difficulty is that the engineering process is continuous, as opposed to the discrete processes usually handled by other expert systems. It is anticipated that these problems can be overcome because of the limited domain of action that the program must cover. Some of the decisions are easily seen to fit within the scope of production rules (Figure 2). For instance, if the main spar of the wing is damaged within 20 inches of the root then the aircraft cannot be repaired within the twenty-four hour period.

The knowledge base must contain the technical dictionary for use by the user interface. This section is used to allow the cognitive engine to understand and to produce understandable responses from and to the users.

The knowledge base must also contain basic engineering parameters and statistics. This section includes material sizes, material substitution tables, material properties, unit conversions, etc.

For the structural analysis problem, the knowledge base must contain the original model of the structure as used by the analysis module. This must also include the intermediate matrices which are modified to reduce the processing time required to reanalyze the design following battle damage. Here is where the first major problem occurs . The analysis program is designed to use large arrays, and the position of elements within these arrays contains some of the information. This information is not in a form that is easily used by the cognitive engine. Also, this information is not in a form easily understood by the technician, more information is needed. Since the technician uses terms like upper spar cap, lower wing skin, etc. the expert system must also use these terms. Therefore, it was decided to use a frame representation technique for the model of the structure. This allows easy conversion into the model that the analysis program understands. The following is a list of the different frames and the information they are to contain.

ELEMENT FRAME
    Part_name
    Element_type
    Nodal_boundaries
    Material_type
    Stresses
MATERIAL FRAME
    Material_name
    Modulus_of_elasticity_tension
    Modulus_of_elasticity_compression
    Density
    Poisson's_ratio
    Ultimate_tensile_stress

    Ultimate_compression_stress
    Yield_stress_tension
NODAL FRAME
    Node_number
    X_location
    Y_location
    Z_location
    Deflections

The only problem encountered with this representation is that access to information based upon the X,Y,Z location of damage is not efficient. This is a minor problem which can be addressed following the implementation of the "breadboard" system.

Since there is at most 24 hours to accomplish the assessment and repair of damage, it is a necessity that the assessment phase be completed as quickly as possible. In order to accomplish the analysis the knowledge base must contain the loads associated with the different mission profiles. One should note that the amount of data available in the knowledge base would be useful intelligence for the enemy, and a method should be researched to determine the best way of protecting this data.

Cognitive Engine

This section deals with the cognitive engine which controls the operation of the entire system. The cognitive engine in this system will probably be different from the engines found in the medical diagnostic systems. In the medical systems it is possible to start with a basic statement of the problem, determine some facts and deduce the problem. In the assessor cognitive engine this process does not hold. The problem is the easy part, usually quite obvious, like the tail is missing. The hard part is the repair of the problem. In medical systems there is usually only one correct way to cure the problem, or the cure is left to the doctor. Figures 1 and 2 [WILPER 1983] show the procedure used in the assessment of structural damage. These figures seem to indicate that systems of EMYCIN would work. However, in the assessor engine, the repair must be specified by the system. Also, there are many possible and acceptable solutions, based upon the materials, tools, and skills available. This makes the problem more complicated. However, to help this problem in the structural area, the Flight Dynamics Laboratory is developing a computer program to assist in the design task. It is now necessary for the cognitive engine to provide the control between the analysis program and the repair program. An interface must also be established with the technician in case the necessary parts, tools, or skills are not available for the prescribed repair. In this case the program must be

capable of providing an alternate repair.

This section has described the major areas which must be handled by the cognitive engine. It should also be noted that a the cognitive engine is to be as generic as possible so that the same computer system can be used on many different weapon systems with only a change in the database.

User Interface

The user interface for the battle damage assessor system need not be complicated. First, it must support the acquisition of knowledge from the expert. It is anticipated that this will not be a field function. Therefore, it need not be implemented in the portable system. The upgrades to the knowledge base can be provided by supplying new media. It should be noted that the portable system is not designed for the technician to use the analysis program directly. To do this effectively, the technician must have had the training associated with an engineer, which violates the assumption that an engineer is not available. By not providing access, it may prevent the technician from making incorrect conclusions regarding the repairs which must be accomplished.

The general user interface need not be intricate. It is anticipated that the responses can be supplied from the knowledge base with little intervention. This allows the user interface to be designed so that it does not have to construct an intelligent response, but rather just select the proper template and add the appropriate quantifiers. The user inputs will be from a very small domain.

SUMMARY

This concludes the discussion of the general concepts incorporated in the high level design of the battle damage assessor. As the development of this system progresses, the design will be further refined and defined. The main problem existing with the system is that the end user does not really know what he wants. He is able to define a deficiency, but not the exact requirements to fulfill that deficiency. Only after a prototype system is delivered will the user be better able to define his needs.

The overall goal is to provide the technician with the equivalent of a structural engineering consultant in the field. This involves providing the capability to design and analyze complicated structure. In the past the structure and subsystems have been relatively simple and easy to fix by the trained technician. But, the advanced technological systems of today cannot easily be fixed even in the factory, without the pressures of time, bad

environment, and lack of materials. If our country is to be able to win an armed conflict, it must be the first with the most, and therefore requires this program.

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